21

Fault Characteristics

محمد عوض

Types of Faults:

- تشغيل الـ protection scheme واكتشاف الـ Fault Condition يعتمد بشكل كبير على خصائص الـ fault نفسه.
- بكل تأكيد: طبيعة الـ fault هي العامل الرئيسي في تحديد:

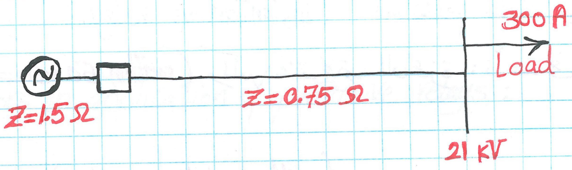
*Nature of Fault determines:

1. Magnitude of Fault Current.
2. Change in Magnitude of Voltages.
3. Change in phase angle Relationships.

- في هذه المحاضرة سنرى: Different types of faults & their effects

* In this Simple one-line-diagram:

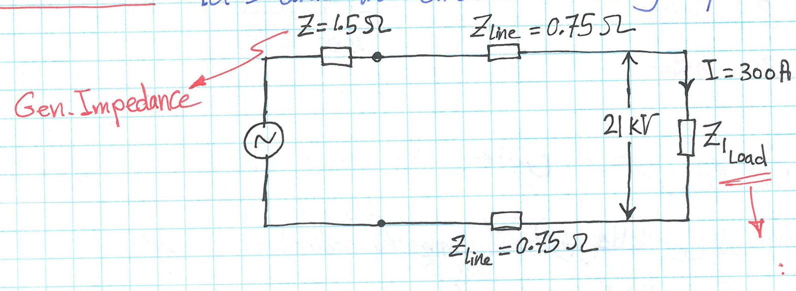
- عندنا Generator يغذّي power عبر C.B و T.L



Load = 300 A

phase to Neutral Voltage = 21 kV

For simplicity: let's draw the circuit as a single phase circuit:

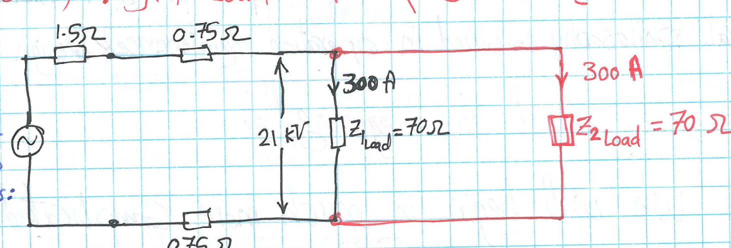


عكس حسابها:

$$\frac{21\ kV}{300\ A} = 70\ \Omega$$

- Load Impedance كبيرة إلى حدٍّ ما مقارنةً بـ Gen. & Line Impedance
- Return line Impedance = 0.75 Ω أيضاً.
- التيار 300 A ← يمر باستمرار في هذه الـ closed single phase circuit.

← ماذا يحدث لو تمّ إضافة Load آخر؟ (70 Ω أيضاً ← بالطبع: ع التوازي)



∴ $I_{total} = 600\ A$

- عند إضافة load ← تقل الـ Load Impedance

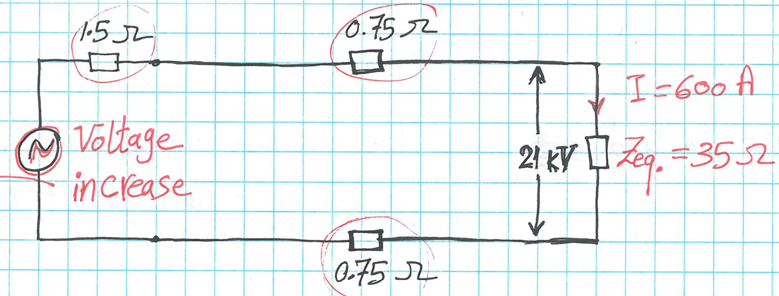
← في هذه الحالة:

The equivalent impedance of these two loads:

$Z_{total} = 35\ \Omega$

22

- كلما يزداد الـ load ⇐ يزداد جهد المولد slightly .



In order to maintain 21 kV at the Load

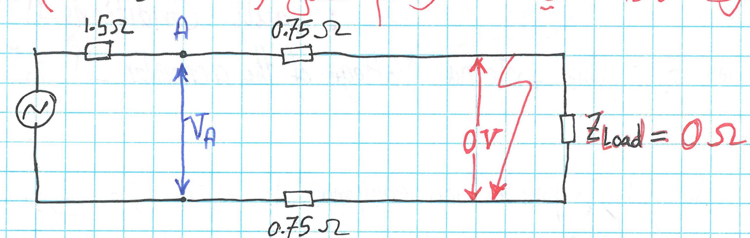
لأن الـ voltage drop بين الـ Gen. والـ Load سيزيد نتيجة لزيادة التيار

∴ للإبقاء على الجهد (21 kV) ثابتًا عند الـ load ⇐ لابد من زيادة جهد الـ Gen .

$$\text{Voltage Drop (V.D) between Gen. \& Load} = (1.5 + 0.75 + 0.75) \times 600 = 1.8 \text{ kV}$$

$$\therefore \text{Internal voltage at the Generator} = 21 + 1.8 = 22.8 \text{ kV}$$

- دعونا نرى ماذا سيحدث لو تمّ عمل (Direct S.C) ← At the far end of the line



∴ Load Impedance تهبط إلى $Z_{Load} = 0\ \Omega$

∴ التيار الذى سيمر خلال هذه الدائرة :

$$I = \frac{V_{gen.}}{Z_{total}} = \frac{22.8 \text{ kV}}{3\ \Omega} = 7600 \text{ A}$$

تغيّر كبير جدًا في (Magnitude of Current) من 600 A إلى 7600 A .

وماذا عن الجهد ؟

لو اعتبرنا أن الـ S.C ليس له Impedance نهائيًا (Z = 0 Ω)

∴ الجهد عليه = 0 V .

وعند النقطة (A) عند بداية الخط ⇐ الجهد سيكون كالتالى :

$$V_A = \text{The internal generator Voltage} - \text{V.D across Gen. Impedance}.$$

$$= 22.8 \text{ kV} - (7600 \text{ A} \times 1.5\ \Omega)$$

$$= 11.4 \text{ kV}$$

نحن نعلم عمليًا أن الموضوع معقّد أكثر من هذا

we have 3 phases to worry about & more ever.

Then, Impedances may be at different angles & therfore, will have to be added vectorially.

2

but, The Conclusions are very clear:

1st Note:

Increase in Load ⇒ - Decreases load impedance.
- Decreases total circuit impedance.

2nd Note:

As a result of s.c ⇒ - Total impedance is greatly reduced.
- Increase in current circulating in the system is dramatic.
(في المثال: زادت حوالي ١٣ ضعف).
- The voltage across the s.c fall to 0 V.
(or - at least - very low value)
- Also, The voltage across the total line decreases.

* عند دراسة الـ Fault Conditions :

نعتبر دائما أن الـ Internal Voltage of the generator يظل ثابتا Constant.

وهذا بناءً على:

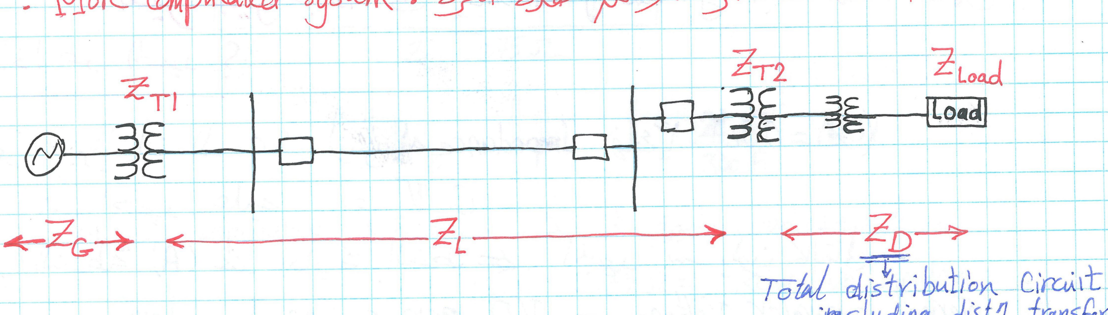
الوقت المستغرق حتى تقوم الـ protection equipment بإزالة الـ fault = صغير جدا.

عمليا: من الصواب أن الـ Generator Automatic Control ممكن تحاول زيادة Generator Internal Voltage لتعويض بعضا من الـ voltage drop down stream ومع ذلك: هذا سيستغرق بعض الـ Seconds.

ولذلك: لايتعارض مع تشغيل الـ protection Relays ولامع دراستنا لـ fault c/c's.

لنتحرك خطوة ونأخذ في الاعتبار: Magnitude & phase angle.

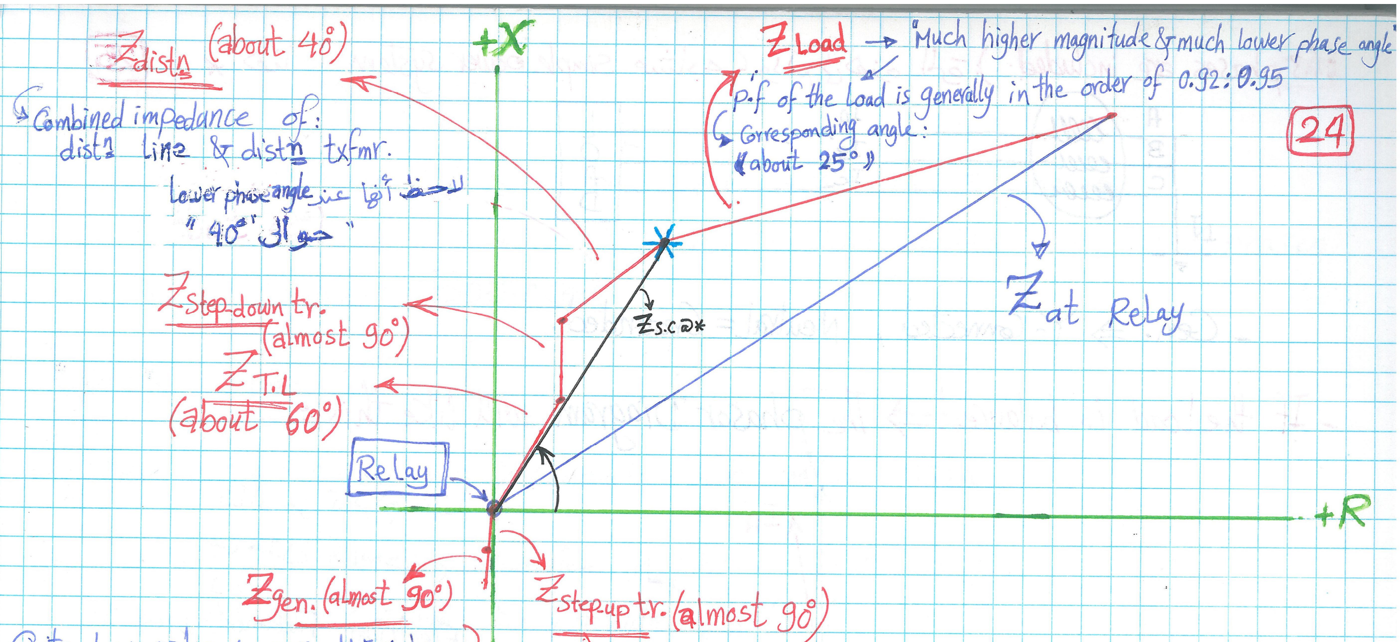
- هذا SLD آخر؛ ولكن هذه المرة: More Complicated system.



« All Z's are line-to-Neutral »

Now, let's plot Resistance/Reactance Diagram (Impedance) as seen by (A Relay located after step-up transformer).

24



معاوقة الـ gen. ⇐ Quite Low value

تتكون بشكل رئيسي من Reactance

∴ large phase angle.

بالتالي: تتكون تماماً من Reactance

ولذلك " close to 90° "

أحمد عوض

* الخط الأزرق يمثل: Total impedance of the Circuit.

* لو في S.C قريب من الحمل (عند * على الرسم):

تستطيع أن ترى أنه سيكون هناك Dramatic decrease في الـ Impedance

ولكن it's phase angle ← increase considerably.

- لو الـ fault أصبح أقرب لـ Source:

The Impedance → is much less

Consequently, The Fault Current → will be much higher.

- من المهم أن تتذكر أن الـ Generator بنفسه له الـ Impedance الخاصة به.

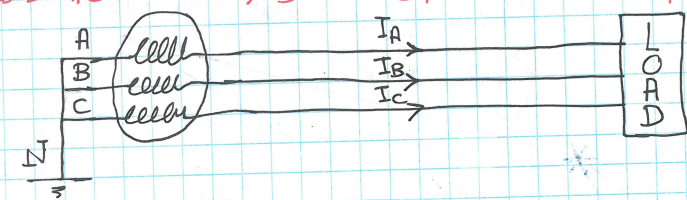
limits the magnitude of fault current even for a s.c on generator terminals.

بالتأكيد: لابد من إزالة s.c بسرعة لتجنب Serious damage.

المثال الذي ننظر إليه بسيط جداً؛ لأننا لم نأخذ في الاعتبار 3 phase system.

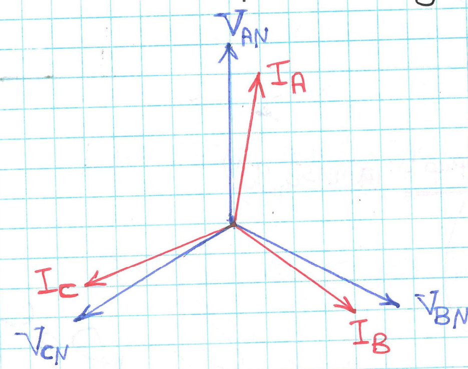
25

* هنا simple power system مشابه ، ولكن في هذه المرة (3 phases are included.):



- Gen. ⇒ Y-Connected , Neutral = Grounded.

- If the Load is balanced ⇒ The phasor Diagram will like this:



متأكد من تذكركم لهذا من خلال دراستكم لـ: Electrical Fudamentals.

When balanced: $I_A + I_B + I_C = 0$

ومع ذلك: لو حصل Fault في هذا الـ system سيسبب:

Considerable Imbalance

$\boxed{\text{What types of Fault Can occur ?}}$

*The most Common are:

1. 3 phase.
2. 3 phase to Ground.
3. phase to phase.
4. phase to phase to Ground.
5. Single phase to Ground.

(أحمد عوض)

$\boxed{\text{3 phase Fault}}$

3 phases (A, B, C) ⇒ Connected together at the fault Location.

⇓

very heavy Current will flow through the Conductors.

but, The System will still Balanced.

26

3 Phase to Ground Fault

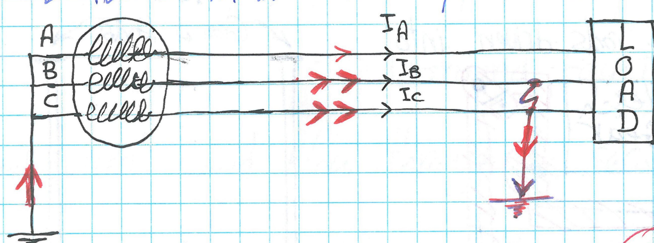
- Considered to be the same as a S.C across all 3 phases.
- The Voltage at the fault is reduced to close to Zero on all 3 phases.
  & It remains Balanced

phase to phase Fault

- There is a S.C between 2 Conductors only (Say: B & C).
  ↳ Heavy fault Current Circulates in phases B & C only.
- phase (A) Can Continue to provide it's load.

phase to phase to Ground Fault

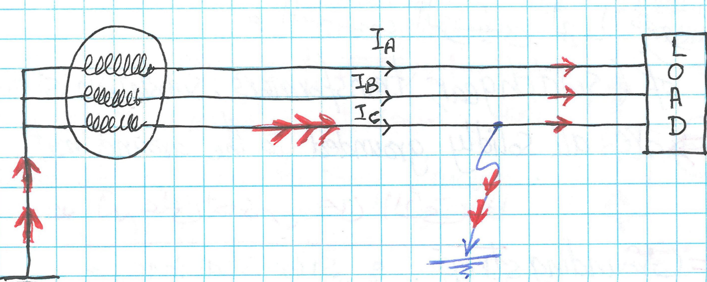
Fault Current flows in the shorted phases and also to ground.



Single phase to Ground Fault

- 95% of faults on the power system are single phase to ground.
- The load will Continue to be supplied by all 3 phases but; There will be a heavy flow of Current to ground from the faulted phase.

This will Circulate back & return up the solidly grounded neutral to the generator.



Break تأخذ The effects of these faults in more details قبل أن نذهب لدراسة

System Grounding

أحمد عوض

27

في الأجزاء السابقة: علمنا أن: The Neutral of the power source ⇐ Solidly grounded

هذا مهم للتزويد بـ path حتى يمر الـ Fault Current.

وهذا الـ Flow يُمكّن الـ Relays من اكتشاف وجود الـ Ground Fault.

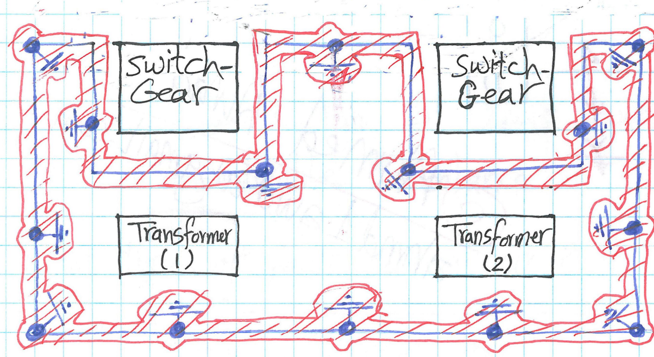
Actually: Not all systems are solidly grounded.

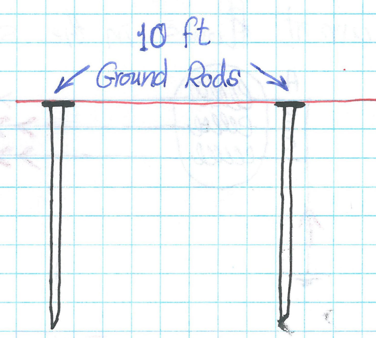
let's look a little closer to common utility practice in (Grounding).

Station Grounds

* what is the nature of this ground ?

- All power system installations such as: power stations & sub-stations are build on **Ground Grids**.





* هذه الشبكة (Ground Grid) تتكون من (metal rods) مزروعة في الأرض على مسافة معينة، ويتم توصيلها بـ (Metallic mesh mat).

ونتيجة لهذا: كل هذه المنطقة (المظللة بالأحمر) ⇐ At the same ground potential

والسبب الرئيسي لهذا هو: Safety.

- The external metallic frame of (switchgear, transformers, substation structure, motors, relay panels, ...) ⇒ are all solidly grounded to the ground mat.

* كم على حذر من الآتي:

في sub-stations: Grounding strap ⇐ لها Considerable current carrying capacity

↳ To provide an easy path for flow of the stray current or fault current to ground.

* The potential of framework throughout the area is at the same ground potential so, providing Safety for personnel working in & around the equipment.

Even: Secondary wiring (for example: CTs & VTs) should be grounded →

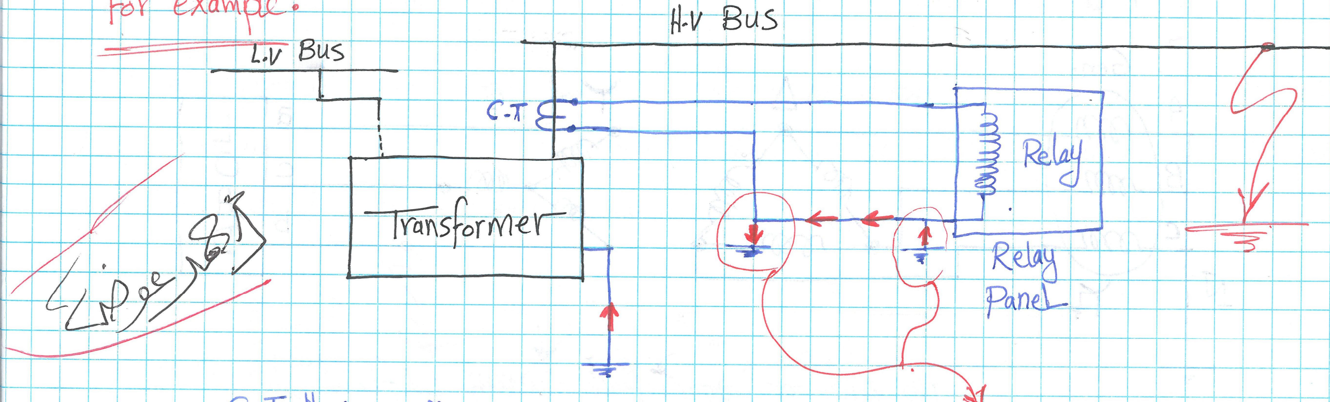
to Discharge any electrostatic potential.

28

ومع ذلك:

من المهم جداً أن نتذكر أن هذه الدوائر ⇐ يجب أن تؤرَّض من نقطة واحدة فقط.

For example:



نفترض أن CT Secondary تمّ تأريضه مرتين
مرة عند الـ C.T.
مرة عند الـ Relay panel.

في هذه الحالة:

The secondary wiring provides a path in parallel with the grounding mat.

دلوقتي: لو حصل (Ground Fault)

Heavy fault current could flow through the secondary wiring

Thereby, causing damage to the secondary wiring & Also, probable mis-operation of relaying equipment.

* عندما يكون تأريض الـ Power System مطلوباً ⇐ يتحقق ذلك بتوصيل (The neutral of the Source Voltage) بالـ (Ground mat).

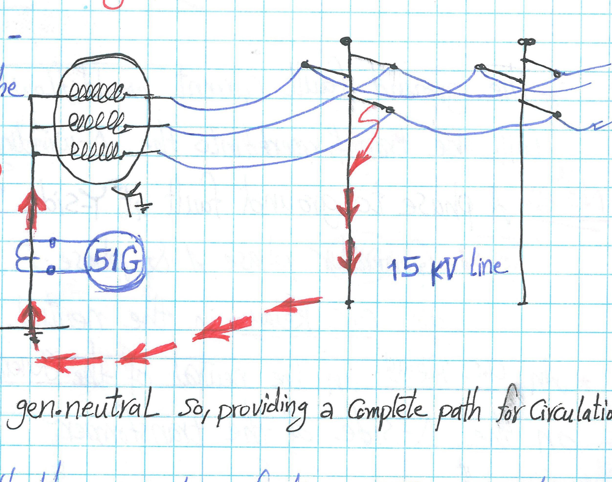
- في هذا الـ (Simple arrangement):

- Gen. ⇐ Y ، ويغذي مباشرة 15 KV line.

- The neutral point of the gen. → Connected solidly to the ground mat at the power station.

لو حصل (single-phase-to-ground fault) على أحد الـ lines
(مثلاً: نتيجة لـ defect of insulator):

- The fault current will run down the tower structure into the ground and Return through the ground to the ground mat of the power station.



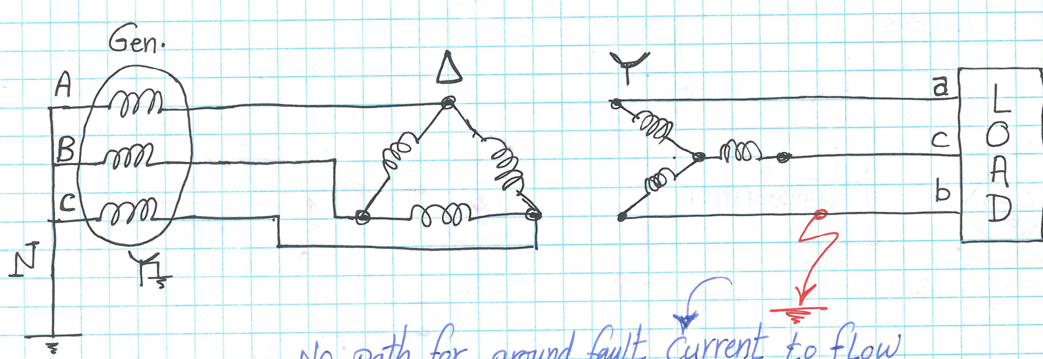
From here: The fault current will flow back into the gen. neutral so, providing a complete path for circulation.

- A C.T is usually connected in the gen. neutral with the secondary feeding a Time O.C Relay.

- This ground relay 51G will need to be co-ordinated with other protection devices on the generator & the line.

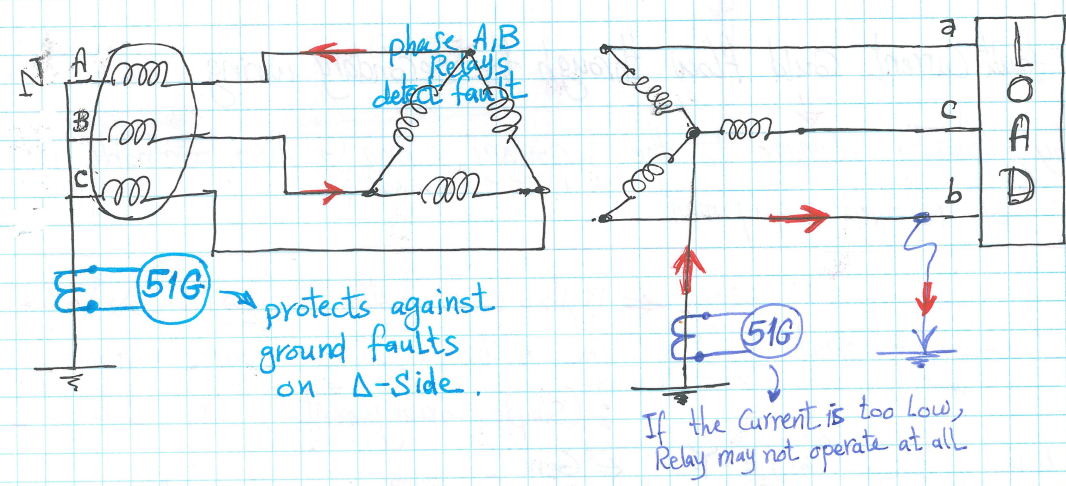
والآن : دعونا ننظر إلى حالة أكثر شيوعًا عندما يكون لدينا
جيث: (Generator) الـ قريبًا من (Δ-Y step-up transformer)

Y-side ⇒ ungrounded & The fault on the secondary.



- There is no path in the transformer H.V windings for ground fault current to flow.
Therefore, The fault will have No effect on generator or T.L currents.

with the Y-side = grounded:



* The ground fault current would flow in the faulted phase of the Y-winding & will be transformed into the Δ-winding as shown.

Note: A phase to ground fault at Y-side $\xrightarrow{\text{manifest itself as}}$ A phase-to-phase fault from the Δ-Side.
Thus: Generator phase A & phase B Relays could detect the fault as could an O.C Relay in the neutral of the transformer.

* An O.C Relay on the neutral of the generator will protect against ground faults on the Δ-side of the transformer.

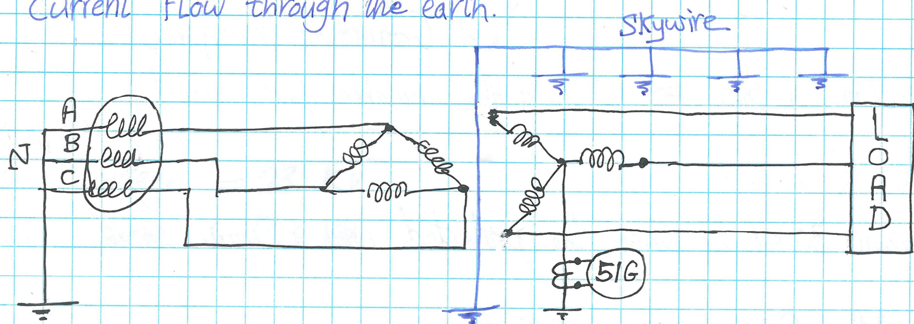
Note: (51 G on Y-Side)
If detect the ~~level~~ of fault current is too low ⇒ This relay may not operate at all.

30

but: After another path is provided:

for example: with H.V T.L ⇒ The steel towers are connected together at the top by a bare ground wires or sky wires (أعلى حاجة على H.V tower ⇐ موصل غير معزول على جسم البرج)

↳ This ground wire goes back to the substation structure which is - of course - grounded to the mat. Subsequently, The ground wire provides a parallel path to current flow through the earth.



© Ahmed Awad

Similarly: on 4-wire distn system:

The neutral (4th wire) ⇒ is usually grounded.

& This - of course - provides an excellent path for ground fault current flow.

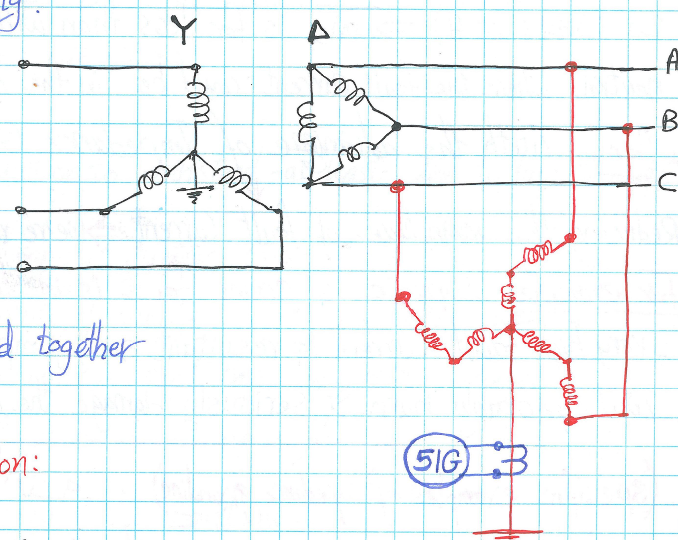
* أنا متأكد أنكم - بالفعل - تفكرون :

↳ Where is the path for ground fault current flow when the transformer secondary is Δ-Connected?

There is No Neutral for grounding.

∴ A Neutral point ⇒ must be provided.

& It's quite usual to connect a (Grounding Transformer) as shown here.



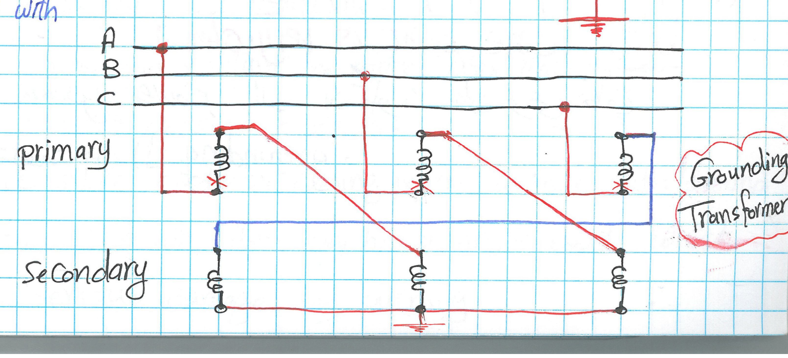
* The transformer works on 1:1 ratio with the primary & secondary is connected together in a ZigZag arrangement.

Here: we see the circuit diagram for this connection:

* (A) primary winding is connected in series with (b) secondary & so on.

⇓

This allows (only ground fault current) to path through.



3

نحن أشرنا إلى أنه (In utility practice):

- The equipment is usually solidly grounded at Voltages above 40 kV.
- At lower Voltages: Sometimes, Equipment is grounded through an impedance to limit fault current.

→ An example is: The generator neutral:

- The impedance may be in the form of
  - A Resistance.
  - A Reactor.
  - A Grounding Transformer.

The main objective of this ⇒ To limit the available fault current.

أحمد عوض

- This method is used in:

Systems up to about 30 kV & where the protected area is quite small.

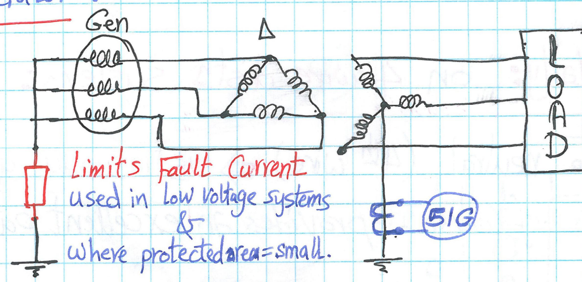
For example: In the case of the generator:

We are protecting against a ground fault within:

1. the generator itself.

or

2. The short line (Cable or Bus) to the transformer.



لإعطائك فكرة عن (The order of magnitude):

The grounding impedance may be sized to limit the magnitude of fault current to (Say: 20 A) ⇒ This is far less than will be in the case of solidly grounded neutral where the fault current could be in the order of (Say: 4000 A).

* Then, with the advantage of Impedance Grounding

Reducing the magnitude of fault current ⇒ we're reducing the amount of damage that it can do.

For example: Suppose a ground fault is in the generator winding itself:

- very high fault current & resultant arc jumping from the winding to stator laminations will probably burn & seriously damage the generator.

سنناقش مستقبلاً -إن شاء الله- (Specific examples of impedance grounding):

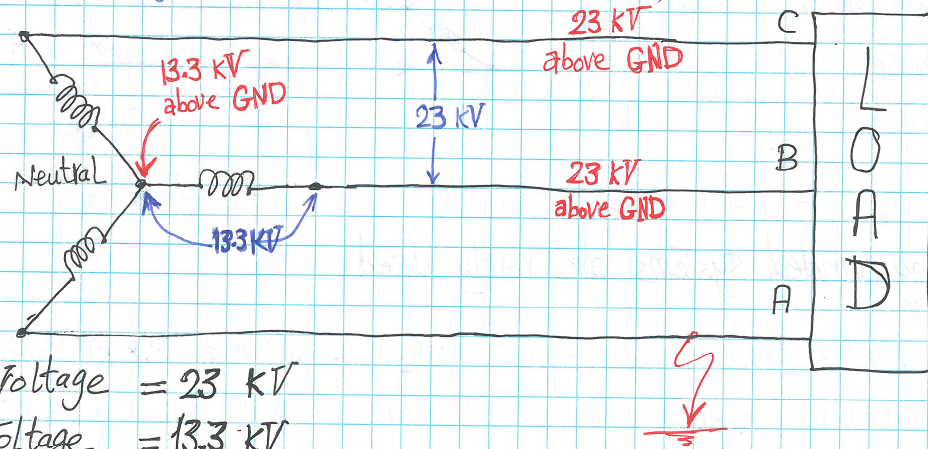
but, one point is very clear:

عند العمل على الـ power system لابد أن تكون على وعي كافٍ بهذه الأنواع المختلفة من الـ grounding.

32

* There is yet one another system that we must mention:
where: There is No grounding at all applied.

لـ البلاد هذه الحالة : (3 phase distn line) يُغذَّى من (ungrounded Y-Connected Secondary) :



L-L Voltage = 23 KV
L-N Voltage = 13.3 KV

→ So, The insulators & spacing of the Conductors (العوازل، والمسافات بين الموصلات على الأبراج) will be designed for (Say: 15 KV).

Now: Suppose: Solidly ground Fault occur on Line (A).

- Reducing this line voltage-to-ground potential (V_{AN}).

⇓

∴ The potential of the neutral will rise to (13.3 KV)
& The line-to-ground Voltage on lines (B&C) increases to (23 KV)

⇓

This will greatly stress & possibly damage the line & equipment insulation.

In fact: where ungrounded systems are used

⇓

It's normal to increase the level of insulation to withstand -at least- line to line Voltage.

but: why would anybody want to render system ungrounded?

* أحد الأسباب ⇐ To ensure Continuity of Supply

For example: An industrial installation which must have minimum outage.

لـ في هذه الحالة: لو حصل (ground) على جزء واحد من الـ system (مثلاً phase (A) على GND)

→ No tripping will occur & power supply will Continue.

→ The 3 phases will Continue to feed the Load & retain the normal phase relationships.

However, This method presents several possible hazards:

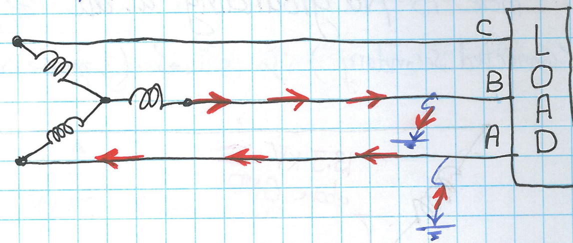
1st: At the fault location: we have a live conductor Coming in the Contact with ground which may be accessible to personnel. More ever, There may be an arc present which if not interrupted will Cause serious damage by burning.

33

- Another problem becomes evident:
- If a second ground occured on another point on the system (say: on another phase)

في هذه الحالة:

we have effectively a S.C between the two phases & This could cause a serious upset to the system.

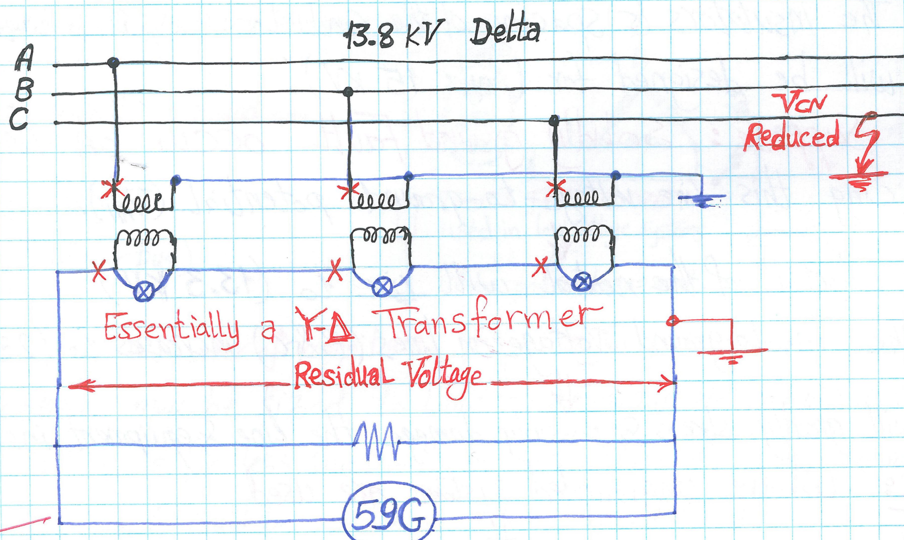


For all of these reasons that we have just explained:

« Ungrounded systems are rarely used »

However: There're sometimes a use of distn system operating at 13.8 kV connected in Δ, & therfore, No accessible neutral point.

In this case: Grounding detection equipment is usually installed as shown here.



Ground over-Voltage Relay

© Ahmed Awad

⊛ Y-Connected primary ⇒ provides (Neutral) for the delta system & this is solidly grounded.

⊛ Δ-Secondary ⇒ Connected in series (This is called a Broken Delta).

- one side is grounded like this. (بالأحمر: ع اليمين)
- The other feeds a Ground over-Voltage Relay.

- If No fault exists ⇒ There is negligible voltage across the relay

لأن الجهود المنتجة في ملفات الثانوي = متزنة فيلغي بعضها بعضًا.

- في حالة حدوث ground fault على أحد الـ Lines: (مثلا على phase(c)):

- The voltage to ground (V_{CN}) on that phase is reduced.

This reduce the voltage across the primary of that phase.

This will cause a reduction of voltage on the associated secondary hence, a residual voltage will appear across the ground over-voltage relay to cause operation.

34

* بالإضافة إلى ذلك:

يمكن وضع (Indication lamps) ⟵ (Across each Secondary)

تعطي indication ⇐ which particular phase is grounded.

The Methods of Grounding

والآن عند هذه النقطة: لنلخص باختصار

* **Solid grounding:**
  - This is the case with most utility systems above 40 kV.
* **Impedance grounding:**
  - Generators may be grounded through an impedance so as to limit the magnitude of fault Current.
* **Non-grounded systems:**
  - Sometimes used in industry or a continuous power supply is required.
  - Distribution systems are sometimes not grounded.
    - In this Case: Ground fault Detection Equipment must be installed.
* **Delta systems:** Can be grounded with Grounding Transformers.
* **Safety Grounding:** is essential

All equipment in power stations, Sub-stations, switch-yards & so on must be solidly connected to the ground mat.

Fault phasor Diagrams

أحمد عوض

* عندما قمنا مبكراً بفحص الأنواع المختلفة من الـ faults والتي تحدث على الـ power system:
  - من الممكن أن يحدث أي واحد من هذه الـ faults في equipment مثل:
    - Transformers.
    - Generators.
    - Circuit Breakers.
  - ولكن تحدث الـ faults أكثر على: Transmission & Distribution Lines
    - As They are more exposed.

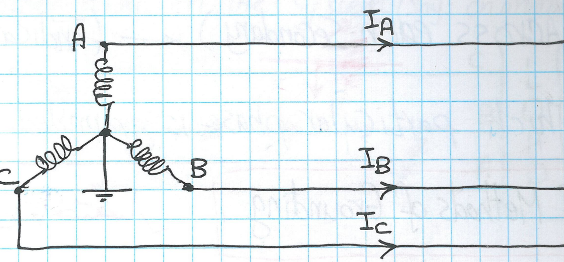
► Now: let's take a closer look at The effects of these different types of faults:

To do this ⇒ we need to study the associated phasor Diagrams.

35

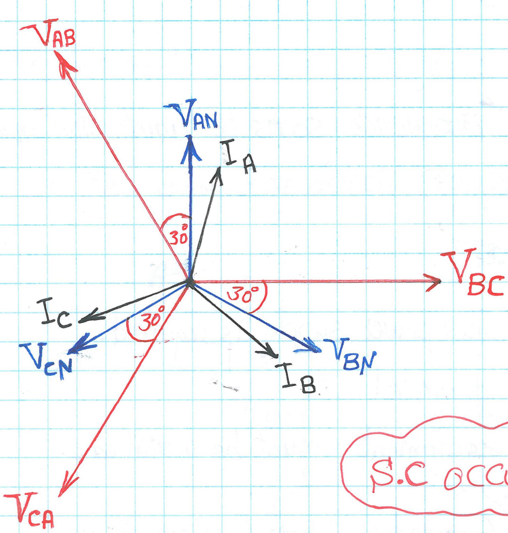
⊛ Simple 3 phase System functioning under normal balanced Conditions : هنا نرى

- تم تبسيط الدائرة من خلال حذف:
  - transformers.
  - Circuit breakers.



- Neutral ⇒ Solidly grounded
  in order to anchor the system Voltage.

* This phasor diagram shows phase relationships & magnitude of (L-N) Voltages.
- (L-L) Voltages are also shown.



لاحظ:

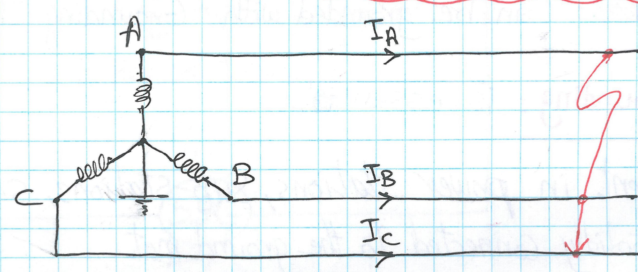
(V_{AB}) يسبق (V_{AN}) بـ $(30°)$

وبالمثل ⇐ The other phase

هذا تعلمناه بالفعل في السابق .

دعونا نرى ماذا سيحدث لو:

S.C occurs across all 3 phases at the end of the Line



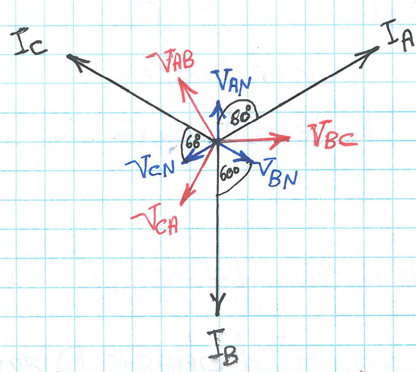
Referring to the phasor diagram:

- We see Conditions at the fault Location

* في دراسة خصائص هذا الـ fault :

It's usual to Consider that there is Zero Load Current on the System.

So, only fault currents are indicated.



* Line Voltages: drastically reduced but, they still maintain the Same phase relationship.

* System: is still balanced.

* Line Currents
- Magnitude: increases greatly.
- phase: It's lagging by approximately 60° on its respective phase Voltage
  why?

This set of phasors also represents:
« 3 phase to ground fault »

36

Angle is determined by the nature of the system impedance to the fault.

→ That is: (Generator + Line) Impedances.

Line Impedance: pre-determines & for:

115 kV T.L ⇒ This is usually about 60°.

HV T.L ≥ 230 kV ⇒ may have impedance angle as high as 85°.

Conversely: L.V Distribution lines ⇒ usually have a line impedance angle of about 50°.

Conditions of phase to phase fault:

والآن دعونا ننتقل لنرى:

S.C between (B&C) lines

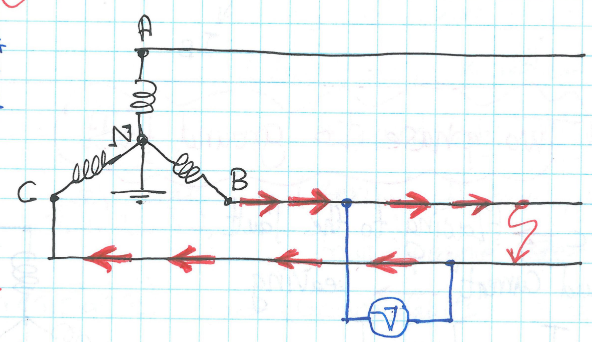
* في هذه الحالة:

- لو وضعت voltmeter بين line B و line C ستجد أن:

Voltage → much Lower than normal.

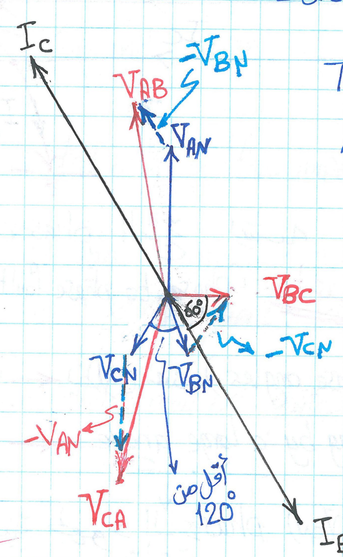
وبالمثل: (V_{BN}, V_{CN}) → will be Lower

- الـ phasor diagram يوضح ذلك:



- S.C drastically reduces (V_{BC}).

This reduces phase voltages (V_{BN}, V_{CN}) & the angle between them to less than $(120°)$



هذا يؤدي إلى تغير في phase relationship ⇐ V_{AB}

هي الفرق بين (V_{AN}) و $(-V_{BN})$

V_{AB} = جمع اتجاهي لـ $[(-V_{BN}) + V_{AN}]$

بتنفيذ هذا الجمع وطرح (V_{BN}) من (V_{AN}) اتجاهيا

نجد أن:

- V_{AB} → moves back in phase angle

And now: Leads (V_{AN}) by less than 30°

- The magnitude of (V_{AB}) is also reduced slightly.

أحمد عوض

We consider this (Phase to phase fault) has seriously distorted our previously balanced conditions.

* دعونا ننظر إلى (Line Currents):

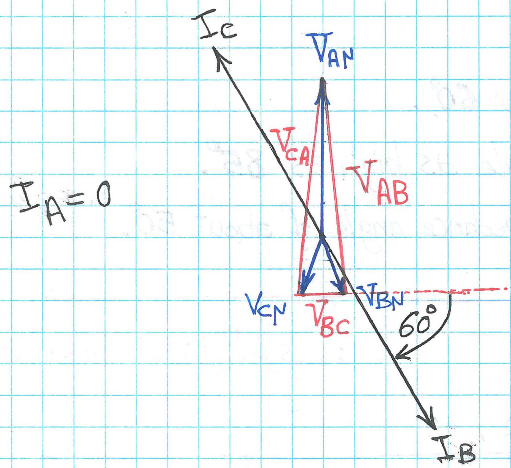
* لأننا نفترض Zero Load ⇐ $I_A = 0$:

* I_B is feeding the fault & this will be lag by approximately 60° on Voltage (V_{BC}).

* I_B يمر من خلال S.C ويعود عبر Line (c) ، ولذلك $I_C = I_B$ in magnitude ولكن عكس الاتجاه فقط (I_C angle تبتعد 180° عن I_B)

37

* يوجد طريقة أسهل لتكوين هذا الـ phasor diagram كالتالى:



أولاً: بتوضيح جهود (L-N).

$(V_{BN}, V_{CN}) \Leftarrow$ depressed فى $\Leftrightarrow$ Magnitude phase angle

نتيجة لـ S.C.

ثانياً: (V_{BC}) هو الخط الواصل بين (V_{BN}) و (V_{CN}) وبالمثل (V_{AB}) و (V_{CA}).

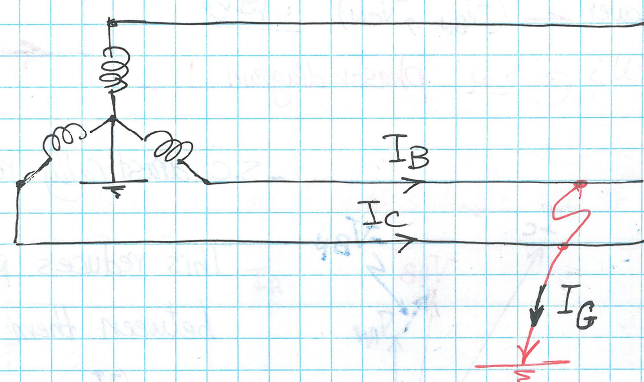
ثالثاً: I_B عبارة عن $(60°)$ من (V_{BC}) و I_C يساويه لكن عكسه فى الاتجاه.

Two phase to ground fault

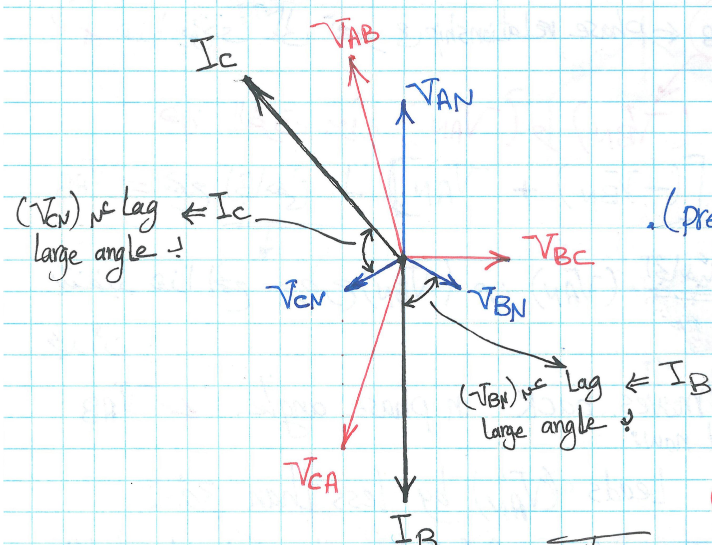
I_B & $I_C \rightarrow$ flowing to the fault.

I_G "Ground Current" $\rightarrow$ Leaving

Thus: $I_G = I_B + I_C$



© Ahmed Awad



- الـ phasor diagram الناتج يشبه الناتج عن (phase to phase fault) ماعدا:

$(V_{BN}, V_{CN}) \leftarrow$ يظلان عند (pre-fault phase angles).

التيارات $(I_B, I_C) \leftarrow$ Lag by a large angle

بالنسبة لجهود الـ phases (V_{BN}, V_{CN}) بتاعتهم.

This is complicated by the fact that Some fault current is flowing to the ground.

Single phase to ground fault

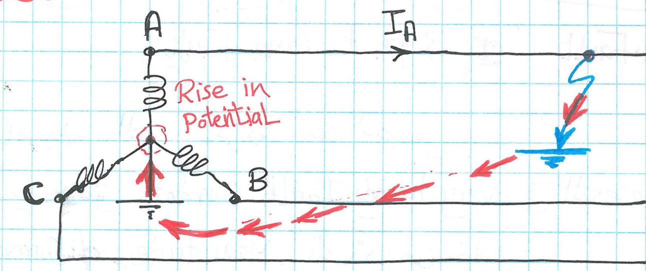
38

كما في الحالة السابقة:

Load Current = Zero

∴ I_B & I_C = Zero

→ They're not shown.



* V_{BC} يظل Normal ، وكذلك (V_{BN}) و (V_{CN}).

هذا لا يحدث في (V_{AB}) و (V_{CA})

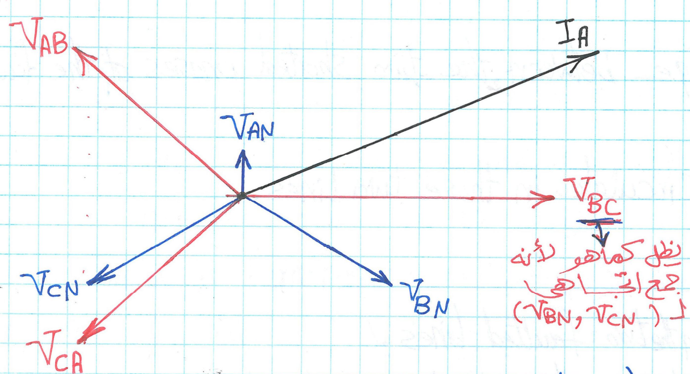
حيث يقل الجهد في هاتين الحالتين

نتيجة لانخفاض الجهد على phase A (V_{AN}).

drastically reduced

ممكن يهبط إلى (Zero).

لو fault impedance = Zero



ولكن: عادة (Ground faults) تحتوي (Some resistance)

ولذلك يظل هناك small Voltage على phase A.

* Ground Current ⇒ will be high.

As it is limited only by (the impedance of the Line + Return path to the grounded neutral).

* The Flow of fault Current through the ground path will actually Cause a Voltage drop & Consequent: Rise in the potential of the neutral at the Source.

This potential shift may be quite small depending on the actual grounding arrangements.

أهم عومك

ملخص: * لرسم phasor diagrams:

① يتم رسم (phase Voltages)

② (Line Voltages) يتم رسمها بجمع اتجاهي لـ (phase Voltages).

③ التيارات يتم رسمها منسوبة إلى (phase Voltages) مع مراعاة:

- العلاقة بينها وبين بعضها البعض.

- زاوية التيار بالنسبة لـ (phase Voltage) بناءً على Fault Impedance.

(أهم عروض) Types of faults & Main effects ملخص 39

3 ph. Fault or 3 ph. to Gnd Fault

- عند الـ Fault location ⇐ يهبط الجهد قريبًا من الصفر.
- يتدفق very heavy fault current في الـ 3 phases.
- كما في كل الحالات ⇐ Magnitude of current يُحدَّد من خلال:
total impedance of the circuit + impedance of the fault.

Ph. to ph. Fault

- The magnitude of the voltage between the two shorted phases at the fault will fall close to zero.
- A heavy fault current will circulate in those two lines.

ph. to ph. to Gnd Fault

- The voltage will fall in the two faulted lines.
- A heavy current will circulate in these two lines & also to ground.

Single ph. to Gnd Fault

- The voltage of the faulted line to ground will fall close to zero at the fault location.
- Heavy fault current will circulate through this line & return through the earth to the grounded neutral.

* The resistance of the fault itself ⇒ important part in determining the value of the fault current.
There may be insufficient fault current flowing ⇐ (Very high) في حالة أنها to operate the relays.

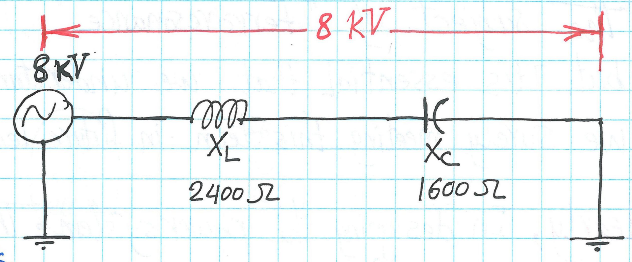
* كل الـ Faults التي ذكرناها تتعلق بـ S.C (Short Circuit)
⇐ يوجد Abnormal Conditions أخرى ناتجة عن O.C (Open Circuit) ولكنها أقل شيوعًا إلى حد كبير.
* لننظر إلى مثال:

لو one phase ← open circuited

في هذه الحالة: سنتقدم بالكلام على ما يسمى بـ «FerroResonance»:
أنتم تتذكرون من دراستكم لـ Electrical Fundamentals أن المصطلح "Resonance"
يشير إلى Combination من (Inductance & Capacitance) والتي يمكن أن تؤدي إلى ارتفاع إلى extremely high voltage levels.

40

For example: Look at this simple series circuit



- Resistance of this particular circuit → negligible.

∴ Total impedance of the circuit:

$$Z = 2400\,\Omega - 1600\,\Omega = 800\,\Omega$$

Remember:
Capacitance & Inductance have opposing effects.

$$\therefore I = \frac{8000\text{ V}}{800\,\Omega} = 10\text{ A}$$

© AHMED AWAD

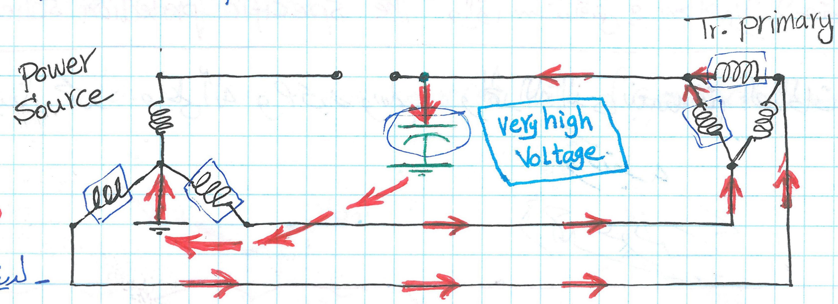
∴ - Voltage across $X_L = 10\text{ A} * 2400\,\Omega = 24\text{ kV}$
- Voltage across $X_C = 10\text{ A} * 1600\,\Omega = 16\text{ kV}$

وبالتالي:

بالرغم من أن (8 kV) فقط هي المطبقة على الـ total Circuit ،
يوجد very high Voltage على individual parts of the circuit
وهذا بدقة مايحدث عندما يكون لدينا Ferroresonance على الـ power system.

Typically : هذا علماً أن يحدث عندما يكون لدينا (Δ-Connected primary of a distⁿ tr.)
في هذا الـ system : الـ distⁿ Line يُغذّى من (Y-Connected Secondary with the neutral grounded)
- وحيث أن هذا distⁿ Line ⇐ Fuses are often used.
- لنفترض Fuse واحد فقط ← ضرب ⇐ ومن ثمّ لدينا one phase ← open Circuited
هذا الموقف يُمكن أن يحدث أيضًا عندما يقوم الـ Line man بفتح feeder switches ← one phase at a time
∴ المحول لسه متوصل بـ two phases ، والتيارات ستسرى بهذه الطريقة :

* The return path to ground is through the Capacitance of the open Line.



والآن انظر بعناية :
- لدينا Inductive reactance في الـ tr. windings
متصلة ع التوالي مع Capacitive reactance بين الـ line والـ ground.
(عليها أزرق ع الرسم).

- Depending on specific values of Capacitance & Inductance:
A very high Voltage could arise across the transformer winding & also, from the line to ground.
⇓
This could damage insulators & the winding of the transformer itself.

هذا الـ Condition من الممكن أن يحدث على الأرجح عندما:
- Voltages are 12 kV and higher.

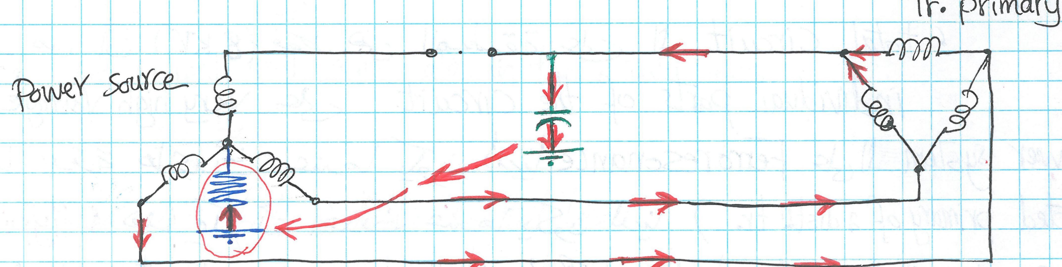
& also when:
- The Line Capacitance is higher → for example: with long lines or where cables are used.

41

* When you think of all the variables in the Circuits:
The subject of "Ferroresonance" is obviously highly Complex
but, It's essential that we understand the principle because
We Surely meeting this term in future lectures when we discuss specific installations.

Clearly, In designing the power system: The engineer tries to ensure that specific values of impedance & Capacitance will not lead to resonant Conditions.

وعلى الفور: أكيد وصلك أن أحد الطرق لتقليل أثر الـ Resonance هو:
to insert a resistance in the neutral of the source transformer.



ولكن: ألم نقل أننا نفضل أن يكون هنا الـ Neutral ← Solidly grounded ؟
وهذا هو مثال آخر على مقارنة مهمة نقوم بإجرائها غالبًا في power system design.

من الضروري أن تصبح familiar مع الـ Concepts المقدمة في هذه المحاضرة
لتعينك على فهم The specific protection schemes والتي ستُناقش في محاضرات لاحقة.

وصلّى الله على سيدنا محمد وعلى آله وصحبه وسلم، والحمد لله الذي بنعمته تتم الصالحات

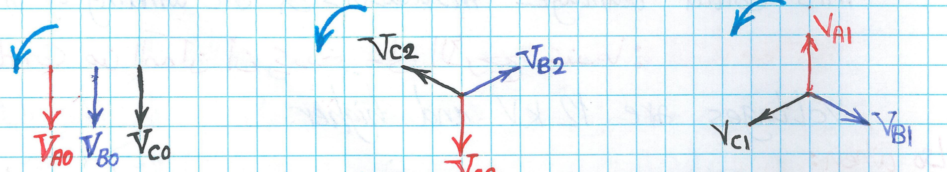
وكتبه
أحمد عوض

Symmetrical Components

أحمد عوض

في الجزء الأخير استخدمنا phasor diagram لنرى كيف تتغير الـ Conditions عند fault Location لتنحرف عن Normally balanced Voltages & Currents.

- The phasor diagram is really geometrical mathematical representation.
- we are now to use another mathematical representation & break the phasor diagram into Symmetrical Components



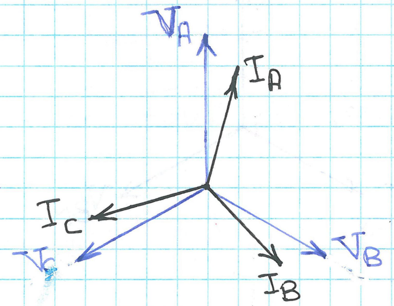
let's allow to go a stage further in our analysis to fault conditions.

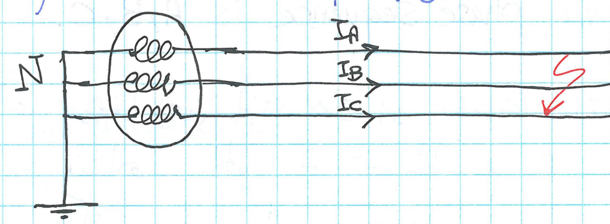
42

كما نعرف : * عند Normal operation :

- power system ← balanced.

- يوجد symmetrical relationship بين جهود وتيارات الـ 3 phases.



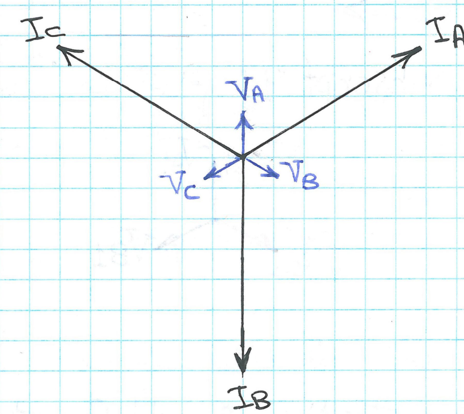


« Generator phasors »
(Normal)

أحمد عوض

* Even with a 3 ph. Fault:

- phase quantities remain 120° apart.



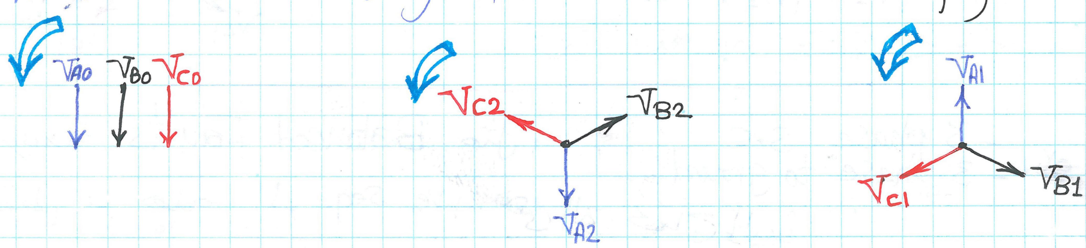
« Fault phasors »

This Symmetrical relationship helps simplify the Calculation of Currents & Voltages under these Conditions.

However, when the system is unbalanced:

Analysis is more Complicated.

we need to divide the Voltages & Currents into: balanced sets of symmetrical Components.



« Zero Sequence » « -ve Sequence » « +ve sequence »

« Symmetrical Components »

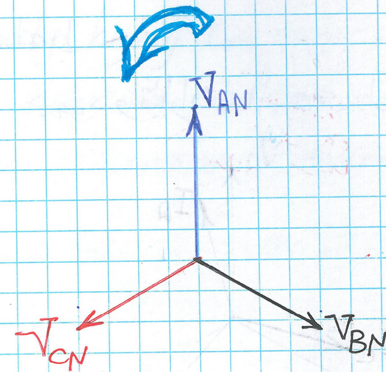
دعونا ننظر الى هذا أقرب قليلاً لنبدأ ب :

نحن بالفعل نعلم أن الـ generator ينتج 3 equal Voltages

which are equal distantly spaced 120° apart.

- وقد أشرنا إلى أن الاتجاه التقليدى
لـ phasor rotation هو Counter clockwise (ccw).

& The normal phase sequence is A, B, C.



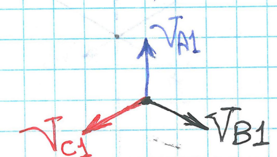
وهذا يعنى أنه من أى نقطة ثابتة فى الفراغ
سنشاهد الجهد A ثم B ثم C ثم A ...
وهكذا بنفس الـ Sequence.

* عند دراسة Sym. Components ⟵ نستخدم دائماً Phase Voltages.

that is ⟶ Line to Neutral or Line to Ground

* فى الـ diagram : نرمز إلى +ve. Seq. باستخدام Subscript "1" $\square_1$.

فمثلاً :

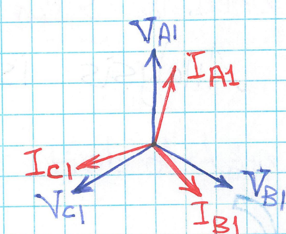


« Generator phasors »
(+ve Sequence)

وعلى نحو مشابه أيضاً تكون الـ Current phasor المُنتجة من الـ generator
Balanced. ⟹ They will look like this.

مرّة أخرى :

I_{A1}, I_{B1}, I_{C1}



* لدراسة Balanced Faults مثل :
- 3 phase S.C
or - 3 phase to ground.

فقط : هذه الـ +ve Seq. هى التى نحتاج إليها.

ولكن : ماذا عن Unbalanced faults مثل (Ph. to ph. fault) أو (a ph. to gnd fault)?
كالآتى :

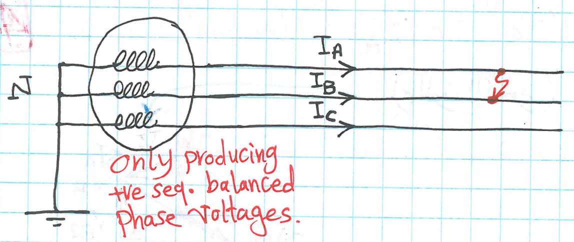
سنحتاج إلى Components أخرى لنقوم بتحليل هذه الـ Unbalanced System Conditions.

دعونا ننظر إلى :

$\boxed{\text{Ph. to ph. Fault}}$

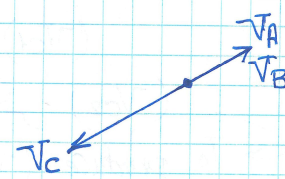
(Where No ground is present)

44



- The Fault is between Line(A) & Line(B).

هذا الـ Voltage phasor diagram يوضح الـ Conditions عند الـ Fault :



« Fault phasor »

- The phase Voltage on line C "V_C" ⟶ Remains at its normal angular displacement.

But

- (V_A , V_B) ⟶ (Low impedance of the fault) يقربوا من بعضهم من خلال

الفرق بين V_A و V_B هو فرق الجهد على (fault impedance)

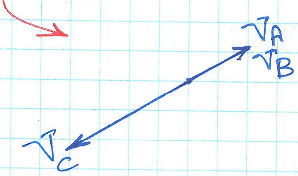
لو اعتبرناها = 0 ⇐ ∴ $V_A = V_B$

أحمد محمد عوض

تذكر :

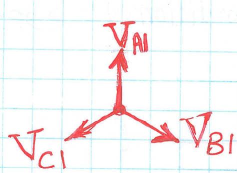
- الـ Gen. يظل دائمًا ينتج +ve seq. phase Voltages
حيث phase Voltages هي (V_A , V_B , V_C).

ولكن عند الـ fault ⇐ Voltage phasor تشبه هذه :

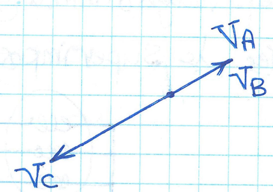


- الجهد عند الـ fault على الـ unfaulted phase
يساوي تقريبًا نفس الـ pre-fault Value.

- ومع الـ ph. to ph. fault تكون الـ +ve seq. Phase Voltage
= حوالي 50% من هذه القيمة



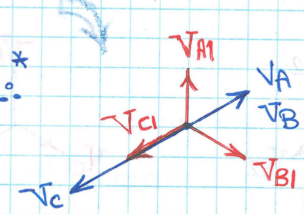
« +ve seq. Fault »



« Fault phasors »

لو نقلنا (+ve seq.) من الشمال لليمين

* سنجد أن هناك Voltages أخرى موجودة عند الـ Fault.
∴ لابد من إضافة (Voltage phasors) أخرى إلى (+ve seq. phasors) للحصول على (Fault phasors).



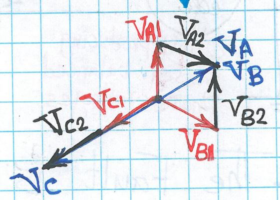
* نستطيع أن نجد The missing Component من خلال دراسة الـ phasor diagram بعناية، وإضافة phasors مناسبة.

45

Now; To transpose +ve seq. fault Voltage (V_{A1}) to (V_A) at the fault:

a phasor must be added in this direction (باللون الأسود)

دعنا نطلق عليه (V_{A2}).



- To transpose (V_{B1}) to (V_B):

يتم إضافة phasor آخر (V_{B2}).

- وبملاحظة (V_C) بعناية:

نجد أن (V_C) أكبر من (V_{C1})

∴ نحتاج إلى إضافة phasor آخر (V_{C2})

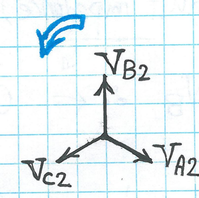
↪ To produce (V_C) at the fault location.

أحمد عوض

⇓

If we bring all of the transposition Voltage Components together, we find:

They are → equal distantly spaced at 120° apart.
They are → of the Same magnitude.



ولكن انظر بعناية آخذاً في الاعتبار Conventional ccw phasor rotation:

الـ phase sequence ⟸ انعكس.

من نقطتنا في الفراغ: سنشاهد phase A ثم C ثم B ثم A ... وهكذا.

تماماً: عكس الـ +ve seq. الذي هو (A→B→C).

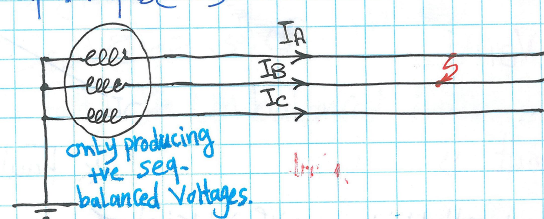
وهذا ما يُعرف بـ (-ve Sequence).

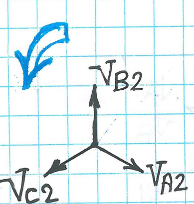
وقيمته تُعطى subscript (2) ($\square_2$).

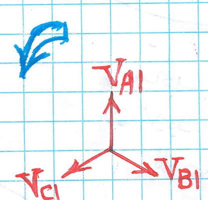
هذا يقودنا إلى خلاصة هامة جداً:

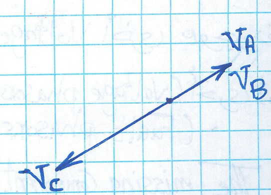
عند وجود (Unbalanced Conditions) ⟸ تُنتج -ve seq. Voltages & Currents بواسطة الـ fault

وتُ superimpose على +ve seq. quantities.







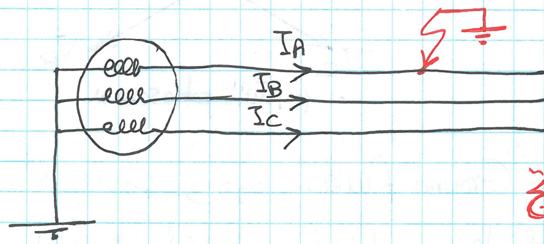


« -ve Seq. Fault » « +ve Seq. Fault » « Fault phasors »

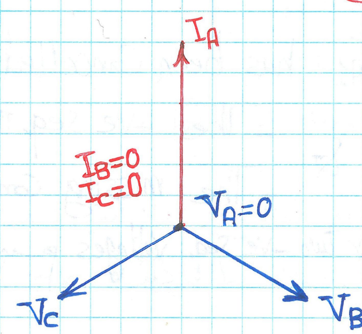
46

Let's move along & Look at:

Unbalanced Fault involving ground



- هنا نرى (Ph. to Gnd Fault) على phase (A).
- وهنا هو الـ Voltage phasor diagram الناتج يوضح الـ Conditions عند الـ Fault :



- الجهد على phase (A) [V_A] يصبح صغيراً جداً ..
[تعتمد قيمته على (Impedance of the fault)]
للتبسيط ⟸ نفرضه = صفر.
- الجهود (V_B, V_C) تظل كما هي إلى حدٍّ كبير.
- التيار على Line (A) يزداد إلى حدٍّ كبير ليُغذّي الـ fault.

لاحظ: رسمنا التيار (I_A) ⟵ in phase with (V_A)

⇓

* للتبسيط: عند استخدام (Sym. Components):
- الـ Fault path يعتبر Ideal pure resistance أو pure inductance

خلال هذا الجزء: نفترض أن الـ fault path يتكون من resistance فقط.

ولذلك: The current in phase with the voltage.

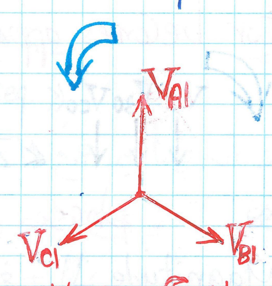
- في الحالتين: The current in Lines (B&C) = Zero

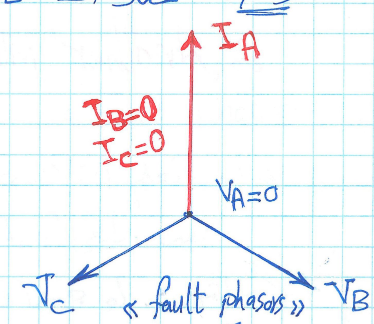
حيث نعتبر الـ system Load = Zero.

(أحمد عوض) ahmd1awd

---

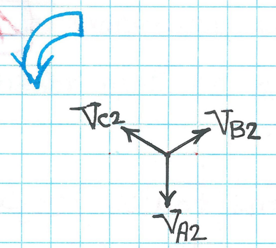
* الـ phasor diagram يوضح أن الـ system ⟸ Completely unbalanced.
- الـ Gen. مازال يُنتج +ve seq. Voltages & Currents
ولكن عند الـ fault : +ve seq. Voltages تهبط إلى $\frac{2}{3}$ قيمتها قبل الـ fault.



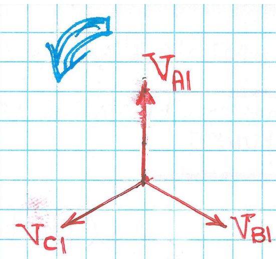


* تذكر الخلاصة السابقة:
أي unbalanced fault له -ve seq. Components تُضاف على +ve seq. Components.

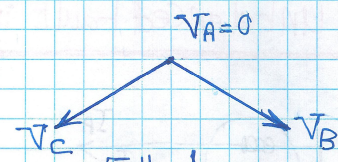
47



« -ve seq. fault »



« +ve seq. fault »



« Fault phasors »

الآن: عند وجود Ground fault ← نحتاج إلى إضافة Another set of Components.

* أولاً: لننظر إلى الجهد على Line (A) عند الـ fault : $V_A = 0$

∴ (V_{A1}) has been Cancelled out by:
- The -ve seq. Voltage (V_{A2}).

&
- The missing Component which we Call (V_{A0}).

الآن: بعد أن وضعنا (V_{A2}) ← نستطيع أن نرسم The other two -ve seq. Voltages
وهما (V_{B2}, V_{C2}) كالتالي:

- نحن نعرف أن هذه الـ Components:
- تتباعد عن بعضها البعض بمقدار $120°$.
- متساوية في الـ Magnitude.
- تدور بالـ phase Sequence : $A \to C \to B$.

الآن: لننظر إلى phase (B) Components:
- نحن نعرف أن جهد هذه الـ phase (V_B) يظل كما هو.

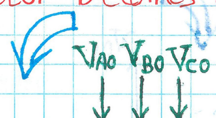
وهكذا :
$$V_B = V_{B1} + V_{B2} + V_{B0}$$
The missing Component

أحمد عوض

Check في الكتاب لتتحقق أن جمع هذه الـ phasors = V_B.

وبالمثل:
$$V_C = V_{C1} + V_{C2} + V_{C0}$$
The missing Component

∴ Another interesting factor becomes apparent:



« Zero Seq. Fault »

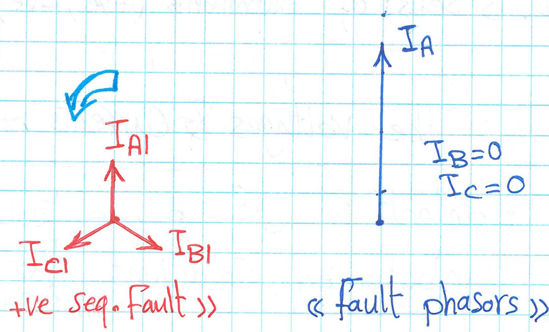
* Component V_0 لكل phase :
- متماثلة في الـ Magnitude.
- نفس الـ phase angle.

في الواقع: هذه الـ Voltage Components ليس لها Sequence على الإطلاق
ولذلك تسمى بـ « Zero Sequence Components ».

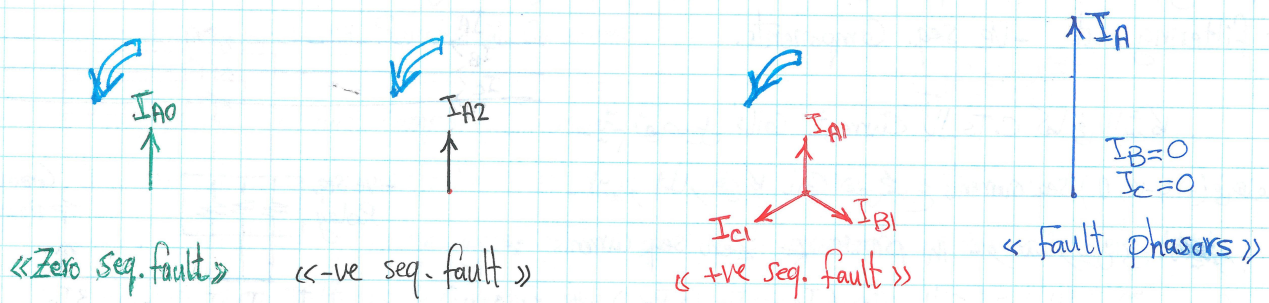
48 * المراجعة : - لإيجاد جهد كل phase عند الـ fault :
اجمع الـ Components ... مثلاً :

$V_A = V_{A1} + V_{A2} + V_{A0}$

والآن : لننظر إلى التيارات :



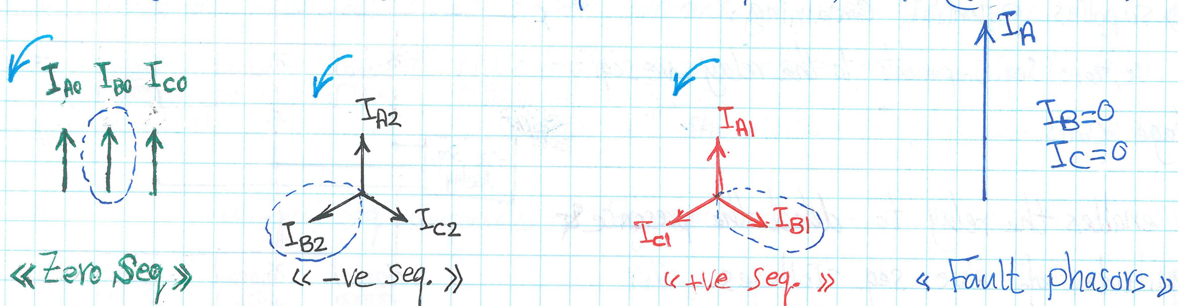
من الواضح أن التيار عند الـ fault (I_A) = حوالي ٣ مرات ضعف الـ +ve seq. (I_{A1}).
∴ الاختلاف بالتأكيد ⇐ وجود الـ two other seq. Components $[I_{A2}, I_{A0}]$ بنفس الـ Magnitude ونفس الـ direction.



بجمع هذه الـ phasors ⇐ تعطي (I_A) :

$$I_A = I_{A1} + I_{A2} + I_{A0}$$

- وحيث أننا قمنا بتحديد مكان (I_{A2}) ⇐ ∴ نستطيع رسم بقية الـ -ve seq. Component.
- وأيضاً نستطيع إضافة (Zero seq. Current Component) متذكرين أنهم دائماً في نفس الـ Angular direction.



* نحن نعلم أن $(I_B=0)$ وهنا لابد أن يساوي جمع الـ phasors : $(I_{B1}+I_{B2}+I_{B0})$.
حيث يلغي $(I_{B1}+I_{B2})$ الـ (I_{B0}) [جمع اتجاهي] ⇐ ∴ Total $I_B = 0$

* بالمثل : لو جمعنا Line(c) phasors $[I_{C1}+I_{C2}+I_{C0}]$ نجد أنها تساوي 0 ⇐ هذا ما يجب علينا توقعه.

∴ There is a heavy flow of Current in the grounded line.
but, there is Zero current flowing in the unfaulted phases.

تذكر : نحن نفترض أن Load = Zero.

49

∴ مرة أخرى : رأينا أن مجموع (+ve, -ve, Zero) Seq. Components لكل phase يُعطي Actual Fault Values.

∴ نصل هنا إلى خلاصة أخرى مهمة جداً :

* عند وجود Ground Fault :

ALL 3 Sets of Components (+ve, -ve, Zero) ⟹ Are present

ولاحظ أن : * For any set of Components:

The voltages & Currents ⟹ equal magnitudes.

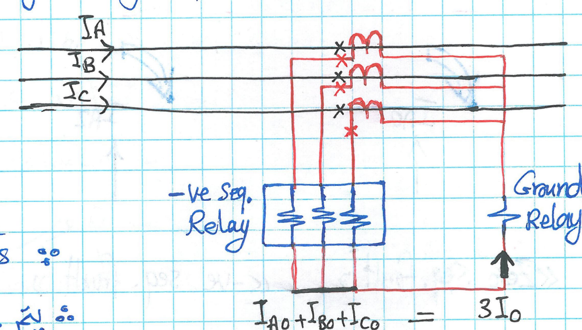
وجود هذه الـ Components يمدّنا بـ tool مفيدة لكي نـ detect :
Unbalanced Conditions & Ground faults.

أحمد عوض

For protection:

يتم تركيب Relays (-ve seq. & Zero Seq.)

- Typically, The -ve seq. relays works by Comparing Voltages & Currents in all 3 phases & filtering out -ve seq. Components.



- يتم توصيل الـ Current Coils بالـ C.Ts كما في الشكل.

- التيار المار في كل Coil هو مجموع (+ve, -ve, 0) Seq. Currents في هذه الـ phase.

∴ Zero seq. Currents ⟸ in phase ومتساوين في المعيار

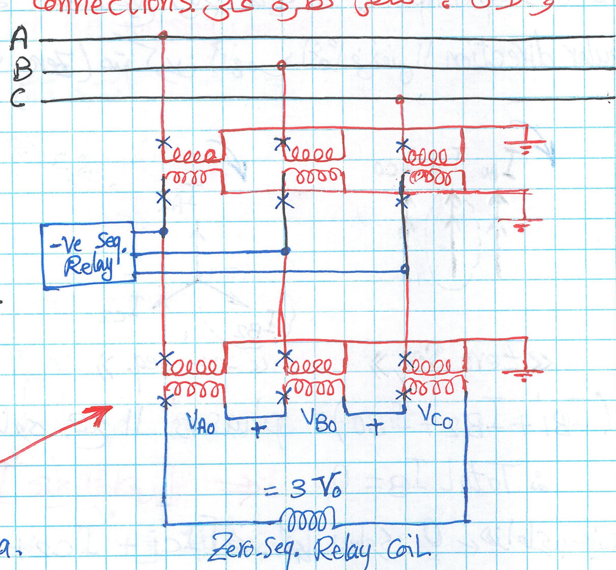
∴ يتم جمع ($I_{A0}+I_{B0}+I_{C0}$) عند النقطة (باللون الأسود).

ويكون الناتج = ($3I_0$) ⟸ يمر في Ground Relay Current Coil.

والآن : لنلقي نظرة على V.T Connections :

- (pri. & sec.) ⟹ Y-Connected + Grounded Neutral.

- Sec. ⟹ supplies potential Containing:
(+ve, -ve, zero) Seq. Components to the relay -ve seq. Voltage Coils.



This enables the relay to detect the presence & magnitude of -ve seq. Voltages.

Additionally: To detect Zero Seq. Voltages:

An Aux. transformer Can be Connected like this:
pri. ⟹ Y-Connected. Sec. ⟹ Broken Delta.

- The zero seq. Voltage in each phase is submitted & fit to the voltage coil in the ground relay.

50

سوف نتكلم عن هذا (لماذا نستخدم هذه الـ Relays) أكثر في المحاضرات المستقبلية -إن شاء الله-.
- نحن نشير إليها للتطبيق عملى على دراسة الـ Sym. Components.
بالإضافة إلى استخدام (Sym. Components) كأداة رياضية لتحليل الـ Fault Conditions.

هدفنا الرئيسى هنا هو:
تقديم مفهوم الـ Sym. Components وتوضيح كم هى مفيدة هذه الطريقة في تحليل الـ Fault Conditions.

* When faults do occur:

- The power system no longer operates with beautiful sine waves & balanced phasors.
At any instant in time: we may have Voltages & Currents going into several directions with magnitudes & phase angles being imposed off in each other
→ Breaking the quantities down into sym. components helps us to visualize the Conditions.

In Fact: Any unbalanced System of Currents & Voltages Can be represented by a Combination of (+ve, -ve, Zero) Sequence Components.

يوجد بعض القواعد الأساسية التي علينا تذكرها عند التعامل مع هذه الطريقة:

Basic Rules for Using Symmetrical Components

أحمد عوض

1. Only phase Voltage Components used.
2. Load Current is Considered to be Zero so that only fault Current flows.
3. Study is Simplified if phase angle of the fault path impedance is taken as Zero.
4. Only +ve seq. Voltages & Currents are created in the generator.
5. Under perfectly balanced operating Conditions, only +ve seq. quantities are present throughout the system.
6. -ve seq. & Zero seq. quantities are considered to be generated at the fault.
7. With unbalanced Conditions: -ve seq. quantities exist as well as +ve seq.
8. Where a ground fault exists, All 3 types of Sym. Components are present that is: +ve seq., -ve seq., Zero seq..
9. Zero Seq. quantities have the Same phase angle in every phase at any instant in time.
10. Summation of the (+ve, -ve, Zero) seq. quantities will show Voltage & Current Conditions at the fault.

* الـ chart التالية توضح The (+ve, -ve, Zero) Seq. Components of Voltages & Currents للـ Fault Conditions الأكثر شيوعاً.

→ Please take a time to go Carefully to each one of these items until you satisfied that you understand the Various Combinations of (+ve, -ve, Zero) Sequence Components.